Journal of the Civil Engineering Forum, May 2022, 8(2):169-178
DOI 10.22146/jcef.3491
Available Online at https://jurnal.ugm.ac.id/jcef/issue/archive

Shear Strength and Durability Behaviors of Compacted Weathered Clay Shale Mixture Using Portland Cement

Pintor Tua Simatupang [1,*], Idrus M. Alatas [2], Ayu K. Redyananda [2], Eko A. Purnomo [2]
[1]Department of Civil Engineering, Universitas Mercu Buana, Jakarta, INDONESIA
Jl. Raya Meruya Selatan No. 01, Kembangan, Jakarta
[2]Institut Sains dan Teknologi Nasional, Jakarta, INDONESIA
Jl. Moh. Kahfi II, Srengseng Indah, Jakarta
*Corresponding author: simatukm@yahoo.com

SUBMITTED 1 December 2021 **REVISED** 16 February 2022 **ACCEPTED** 6 March 2022

ABSTRACT The use of weathered clay shale often has the potential to cause geotechnical problems as an embankment material, especially slope failures. In order for weathered clay shale to be used as embankment material, the weathered clay shale must be mixed with other materials. An example of a widely used mix is a mix with a Portland cement (PC). In general, this mixture will increase the shear strength of the embankment material. In addition to shear strength, it is very important to investigate whether the material mixture is susceptible to durability. Therefore, this study aims to evaluate the shear strength and durability behaviors of weathered clay shale mixture, using PC. The percentage of this cement was varied and did not exceed 20%, with the mixing material also compacted based on Proctor Standard procedure. This test included the determination of shear strength and durability index at the smaller and larger (dry and wet sides) than optimum moisture content (OMC). Shear strength and durability index were determined by Triaxial and slake durability index tests, respectively. The results showed that the weathered clay mixture with 10% PC and 8% larger OMC led to an increase in the normalized shear strength ($\Delta\sigma/\sigma_3$) and durability index at approximately 300% and 24%, respectively, compared to the original clay shale. This indicated that the optimum shear strength and durability of this shale mixture were highly observed at 10% PC and 8% larger OMC (wet side). This verified also although the durability index increased by 97% with the addition of 20% PC, whose utilization was found to be unrealistic.

KEYWORDS Weathered Clay Shale; Shear Strength Ratio; Durability Index.

1 INTRODUCTION

The use of compacted weathered clay shale often causes geotechnical problems as an embankment material for infrastructure works, especially the slope failure in the farm area of Cariu, Jonggol, West Java, Indonesia. In this condition, the shale is reportedly used on the side of the slope, with the occurrence of failure observed after compaction during the first rain, as shown in Figure 1 (Alatas, 2020). Based on Figure 2, similar occurrences were also observed in 2011, during the construction of the Semarang-Bawen Toll Road, Central Java (Himawan, 2011).

The use of clay shale is not often realized as an embankment material, especially for small-scale works. This is because the material is commonly obtained from the surroundings of the specified location. The shale behavior is not also recognized widely by most people, due to the strength of the original clay material. However, the shear strength significantly decreases after being weathered, leading to its usability as an embankment material. For effective and efficient results, the weathered material needs to be mixed with Portland Cement (PC) to yield increased shear strength. Based on a laboratory test on compacted weathered clay shale from Cariu, West Java, the shear strength increase was determined after the addition of five percentage variations of Portland Cement (PC), namely 0, 5, 10, 15, and 20%. This test was subsequently conducted for the durability index of the material, to determine wear and tear (Wawan et al., 2019) resistance against the causes of weathering, such as the atmosphere and hydrosphere. Wawan et al. (2019) also analyzed the stability of Hambalang weathered clay shale with PC, based on optimum moisture content. For soil improvement, the use of cement is found to be quite old, with the mixture of both materials leading to increased shear strength. Besides this, cement is also used to improve the environment, through the mixture with healthy and contaminated soil, as well as other waste materials. This is reportedly very successful in effectively improving the environment (Nicholson, 2014).

Figure 1 Slope failure on compacted weathered clay shale embankment at Cariu, Jonggol, West Java, Indonesia (Alatas, 2020).

Figure 2 Slope failure at Toll Road Semarang-Bawen, Central Java, Indonesia (Himawan, 2011).

Based on Ciantia and Hueckel (2013), calcarenite (clay shale-like soils) underwent weathering when the pores were filled with water. This showed a decrease in the shear strength to 60% from dry conditions. Castellanza and Nova (2004) also emphasized carbonatic rock based on its mechanical characteristics, through weathered progressive degradation. This was carried out on a laboratory scale by using oedometeric tests. Furthermore, Alonso and Pineda (2006) generally and intensively described the mechanism of clay shale or claystone weathering and degradation, whose mechanisms are mainly explained from a qualitative perspective. In this condition, the changes in stress and suction cycles were believed to be the main contributors. The results thoroughly described the methods by which these changes affected clay shale degradation in tunnels and excavations, after being exposed to the atmosphere and hydrosphere. Therefore, this study aims to carry out the following, (a) Analyze the effect of PC on the increased shear strength of the soil (c and ϕ), which is determined by the parameter's elevated ratio, (b) Evaluate the effect of weathered clay shale moisture content for each provided PC percentage, when compaction is carried out on the shear strength and durability index ratios, and (c) Determine the optimum percentage of PC usage that meets the shear strength and durability index requirements.

2 CHARACTERISTICS OF CLAY SHALE FROM CARIU, JONGGOL, WEST JAVA

2.1 Cariu Clay Shale Properties

The distribution of clay shale in this area is part of the Jatiluhur formation, with the main properties and mineralogy content of the materials shown in Table 1 and Figure 3, respectively. The mineral content in the Cariu clay shale was approximately 24.1% (Kaolinite, Illite, and Montmorillonite), which was quite smaller than the compositions in Semarang (56%) and Hambalang (62%) materials (Nazir et al., 2016). Meanwhile, the largest mineral content in this claystone is Quartz, observed at a value of 57.6%.

2.2 Compacted Weathered Clay Shale

Using the Standard Proctor ASTM D-698, the compaction analysis on weathered Carlu clay shale is shown in Figure 4, where a maximum dry density and an optimum moisture content of 1.94 t/m^3 and 11.52% were obtained. From the

Table 1. Cariu clay shale properties (Purnomo 2020 and Redyananda 2021).

No	Properties	Value	Unit
1	Water Content, Wn	5.06 – 5.18	(%)
2	Specific Gravity, Gs	2.67 – 2.66	-
Atterberg Limits			
3	Liquid Limit, LL	75.49	(%)
4	Plastic Limit, PL	26.63	(%)
5	Plastic Index, PI	48.86	(%)
Grained Size Distribution			
6	Gravel	0.00	(%)
7	Sand	3.76	(%)
8	Silt	35.39	(%)
9	Clay	60.85	(%)
Mineralogy			
11	Quartz	57.60	(%)
12	Kaolinite	13.40	(%)
13	Illite	10.40	(%)
14	Albite	10.40	(%)
15	Siderite	4.60	(%)
16	Calcite	3.40	(%)
17	Montmorillonite	0.30	(%)
18	Dolomite	< 0.10	(%)

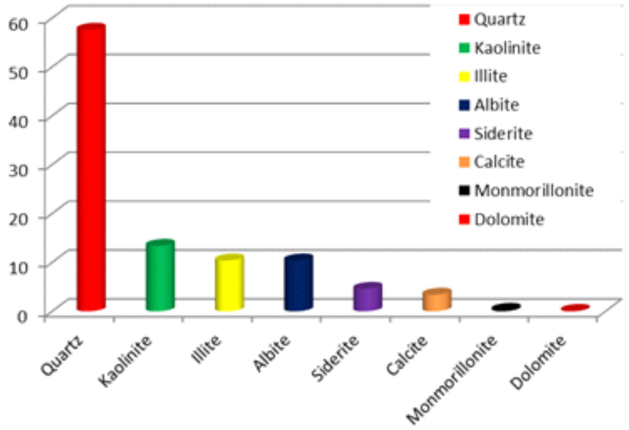


Figure 3 X-ray results of Cariu clay shale.

Jatiluhur formation, this density was only about 84.7% of the shale's average natural dryness (2.29 t/m^3), according to Alatas (2016). This showed that the claystone belonged to the Jatiluhur formation group, indicating the material's low shear strength.

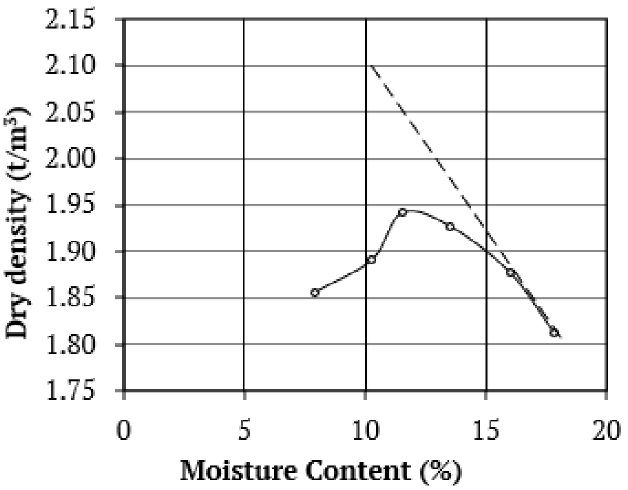


Figure 4 Standard Proctor compaction of Cariu clay shale.

2.3 Disintegration Ratio Clay Shale

The disintegration ratio (DR) describes the physical transformation of the normal clay shale to a weathered material. This indicates that the initial large grain of the shale is found to be smaller due to weathering. Using the grain size distribution test, the initial and weathered conditions were also determined by the percentage retained weight, as shown in Figure 5 (Erguler and Shakoor, 2009). This reflected that DR was mathematically expressed as the ratio between the weathered and initial grain size areas.

Based on Shakoor and Gautam (2011), the changes in the disintegration ratio of various clay and silt rocks were initially published, with Erguler and Shakoor (2009) subsequently proposing the effect of slaking on clay rock durability. Sadisun et al. (2010) also reported the properties of the fresh claystone exhibiting a progressive level of physical weathering, during its interaction with the hydrosphere and atmosphere. Furthermore, Alatas et al. (2015) investigated the DR changes in the Hambalang clay shale, as shown in Figure 6. This indicated that the disintegration ratio was almost unchangeable when the drying process is only involved, as a transformation of 0.91 was solely observed for 80 days. However, DR was found to significantly decrease during the wet and dry cycles of the weathering processes. For example, soaked DR reduced from 0.99 to 0.49 through one cycle of the wetting-drying process, during the dry period of 24 days. This confirmed the occurrence of approximately 50% disintegration.

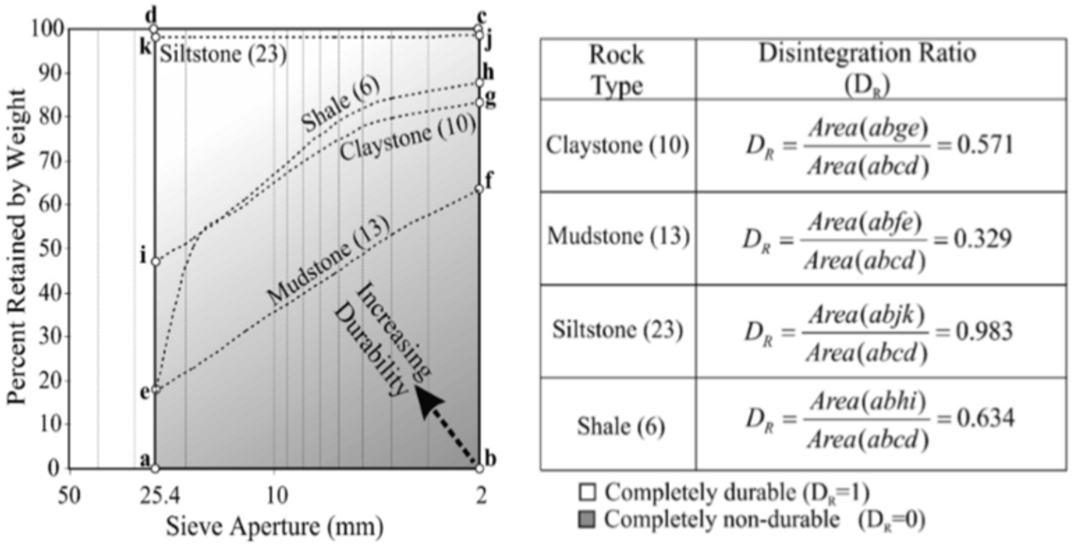
Despite these conditions, the degradation in cohesion parameters is still observed in the Semarang-Bawen clay shale, due to the weathering processes (Alatas et al., 2015). This indicated the reduction patterns of shear strength parameters from unsaturated to saturated conditions. Figure 7 shows the transformation of cohesion in the dry period of 0-80 days, for peak and residual total stresses (US–PTS and US–RTS) without and with releases. This exhibited the occurrence of a significant cohesion change in the residual condition, compared to the peak stress. However, a much greater reduction occurred in the residual condition with stress release. When the change in cohesion is considered to be linear, the undrained cohesion equation, c_u, is then included as a function of drying time (DT). Therefore, the undrained cohesion equation for peak stress is expressed by c_u, with the residual condition without and with stress release being represented by c_{urp} and c_{urf}, respectively.

Figure 8 shows the changes in the disintegration ratio of stabilized-weathered PC clay shale, after 9 wetting-drying cycles (Alatas et al., 2019). This proved that PC was very effective in reducing the DR of compacted-weathered claystone, with the stability of the treated Cariu material found to be very useful. Without the addition of Portland cement (0%), the DR for the naturally weathered clay shale in one cycle was quite close to 0.1, although the next phase did not cause many transformations. This showed that the increasing amount of PC led to the gradual and effective reduction of the disintegration ratio. At 12% PC, the slight transformation was only observed for the DR. This confirmed that the disintegration ratio function of drying cycles was approximated as a linear relationship. Additionally, the selected moisture content was only used for optimum conditions, with more results subsequently analyzed in this present report.

3 RESEARCH METHODS

Figure 9 shows the experimental stages of the analysis for better understanding. This was conducted on original and PC-based weathered clay shales at 5, 10, 15, and 20%. Original undisturbed and disturbed soils were also analyzed for slake durability index, as well as compaction and Triaxial, respectively. Subsequently, the PC-based weathered clay shale was pre-soaked for 3 days before testing, as all utilized soil samples underwent Triaxial, slake durability, and Atterberg limit analyses.

In this experiment, fresh and weathered clay shales were used to analyze both undisturbed and disturbed samples, as the slake durability



Rock Type	Disintegration Ratio (D_R)
Claystone (10)	$D_R = \frac{Area(abge)}{Area(abcd)} = 0.571$
Mudstone (13)	$D_R = \frac{Area(abfe)}{Area(abcd)} = 0.329$
Siltstone (23)	$D_R = \frac{Area(abjk)}{Area(abcd)} = 0.983$
Shale (6)	$D_R = \frac{Area(abhi)}{Area(abcd)} = 0.634$

Figure 5 (a) Fragment size distribution curves for some clay-bearing rocks and (b) mathematical derivation of the disintegration ratio (Erguler and Shakoor, 2009).

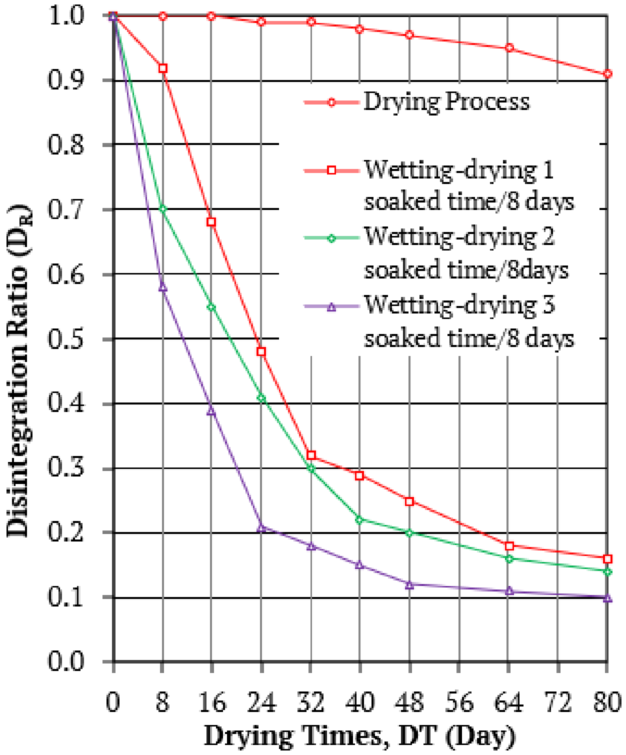


Figure 6 Transformed disintegration ratio of Hambalang Clay shale after weathering (Alatas et al., 2015)

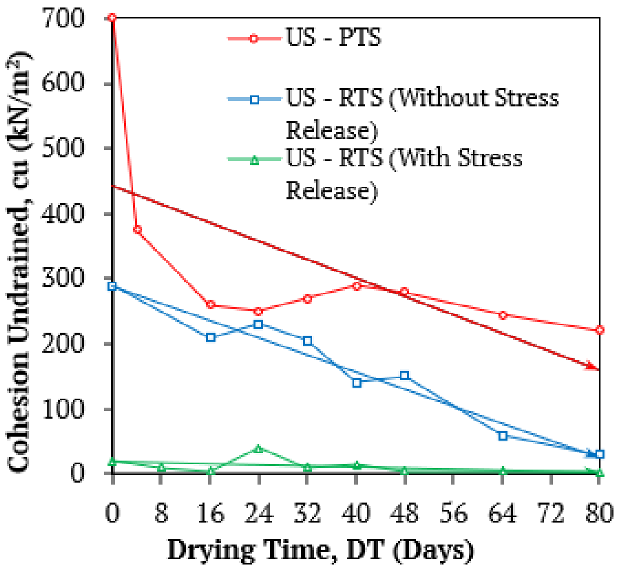


Figure 7 Unsaturated undrained cohesion degradation due to the dry weathering process of Semarang-Bawen clay shale (Alatas et al., 2015).

analysis was initially performed. The disturbed soil sample was also subjected to the index properties, compaction, specific gravity, grain size distribution, and Triaxial UU analyses. The results showed that the weathered shale naturally contained clay, which often used undrained shear strength in embankment conditions due to its

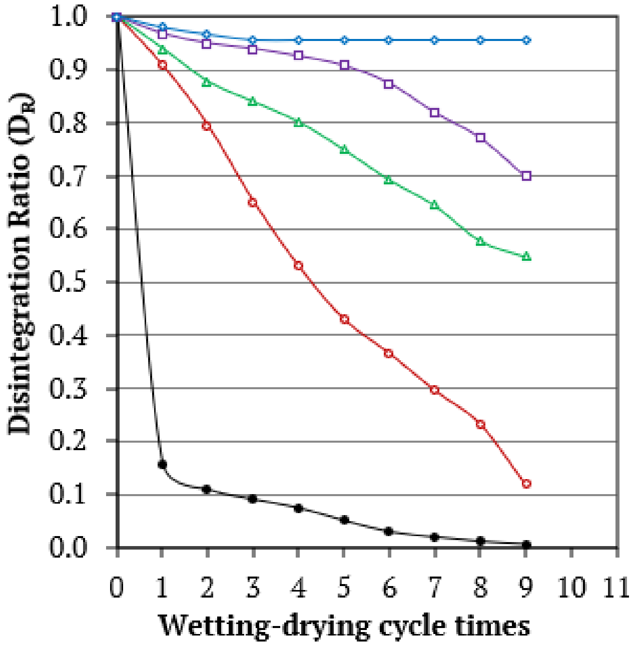


Figure 8 The changed disintegration ratio of Compacted PC-based Hambalang weathered clay shale for wetting-drying cycles in optimum water content (Alatas et al., 2015)

critical value. Furthermore, the compaction test was carried out through the SCMT (Small Compaction Mold Testing), where the weathered sample had a diameter and height of 3.5 and 7.0 cm, respectively (Alatas, 2006). With the adjustment of energy, this test provided similar results as the standard ASTM D-698 and D-1557 analyses. The soil samples produced from the test, i.e., compacted weathered clay shales, were then analyzed through the Triaxial and Slake Durability Index Analyses. These were conducted to describe the shear strength and durability behaviors of the weathered clay shale. The slake durability index test was also carried out according to the ASTM D-4644-16 Standard, with the test equipment shown in Figure 10.

4 RESULT

4.1 The Compacted PC-based Weathered Clay Shale

Figure 11 shows the compaction test on the PC-based weathered clay shale through the SCMT method, where a change was observed in the optimum moisture content (OMC) due to an increase in the cement percentage. This indicated that the OMC with PC > 5% was smaller than the optimum moisture content of the original

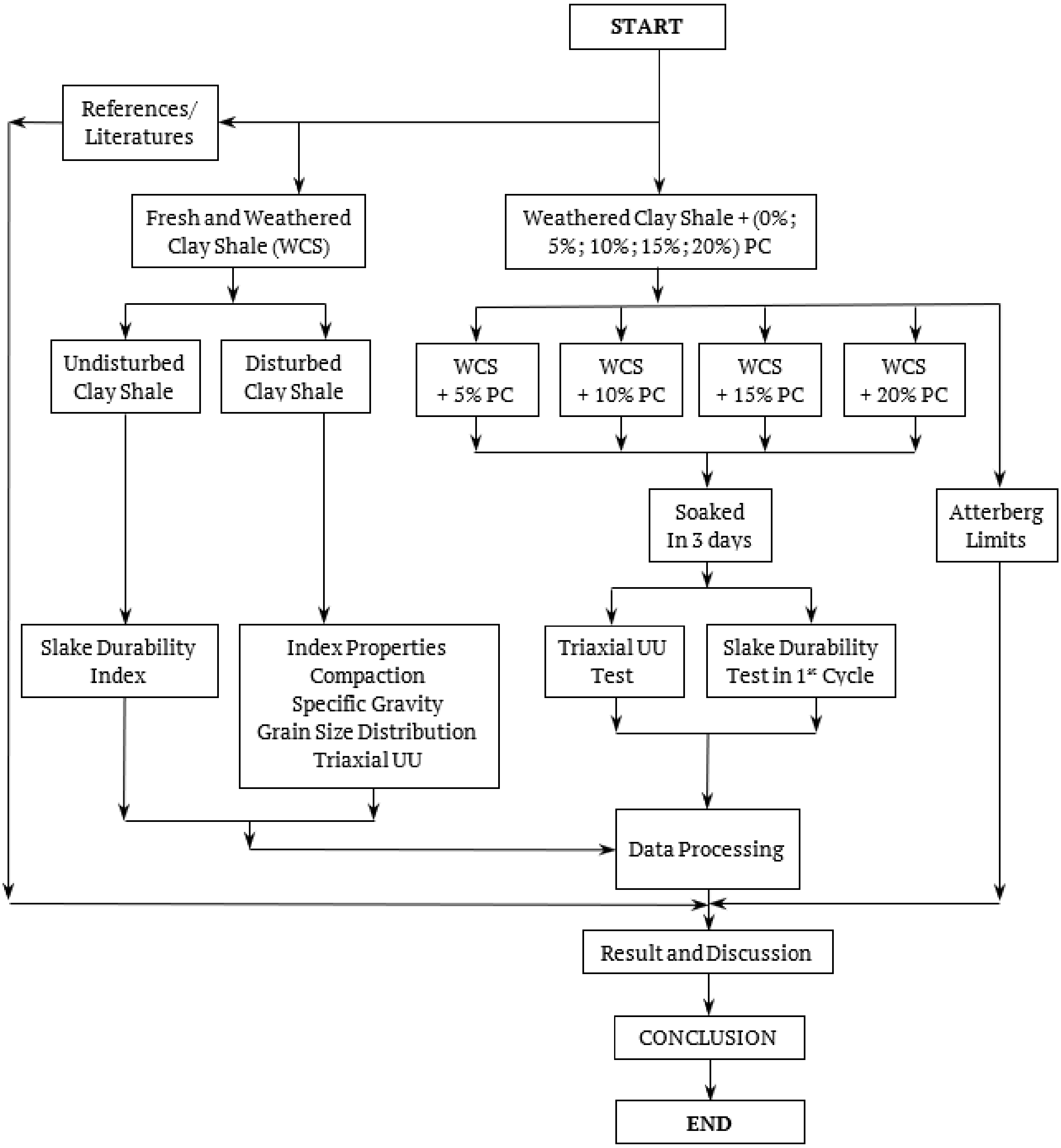


Figure 9 Flowchart of the experimental stages

weathered sample. It also indicated that more PC in the weathered clay shale led to high hydroxyl reactions, which caused a subsequent decrease in the OMC.

The compaction tests for various PC percentages were also carried out on 3 samples with varying moisture content, where the differences obtained in each utilization are shown in Table 2.

In the PC-based sample, the Atterberg behavioral limits are shown in Figure 12, where changes in the LL (liquid limit) led to the transformation of the Soil Classification, due to the addition of PC percentages in the weathered clay shale. Based on the Unified Soil Classification System, the original weathered claystone belonged to the CH group, which changed to CL after mixing with PC.

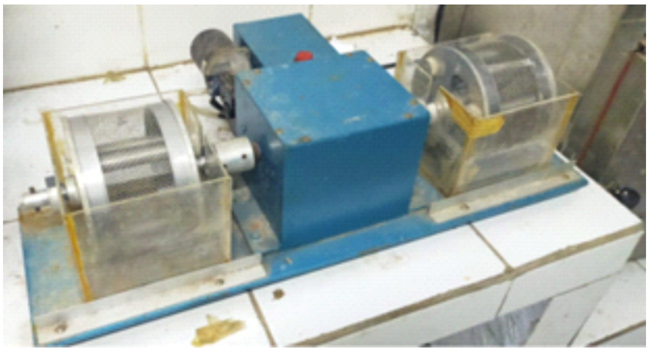


Figure 10 The apparatus of slake durability index

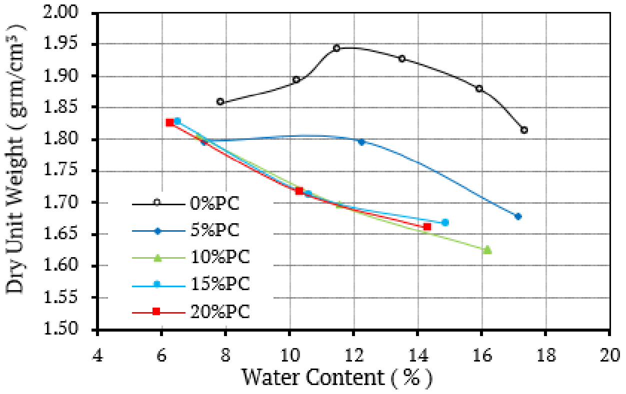


Figure 11 Compaction behavior of mixing weathered clay shale with various percentages of PC

Table 2. Variation of moisture content on the compaction of 3 PC-based weathered samples

% PC	The water content of the sample specimen		
	1	2	3
0	< w opt	w opt	> w opt
5	< w opt	w opt	> w opt
10	w opt	> w opt	» w opt
15	w opt	> w opt	» w opt
20	w opt	> w opt	» w opt
Remark	w opt due to added % PC "< w opt" is 4% less than w opt "> w opt" is 4% more than w opt "» w opt" is 8% more than w opt		

4.2 Shear Strength Behavior of Compacted PC-based Weathered Clay Shale

The behavior of the shear strength parameters, such as cohesion (c) and internal friction angle (∅), on the compacted weathered clay shale with varying PC and moisture content, are shown in Figure 13 and Figure 14, respectively. These parameters were determined by Triaxial Unconsolidated Undrained (UU) test, which is routinely used for clayey soil based on ASTM D-2850. Additionally, three moisture content conditions were analyzed with various PC percentages, namely dry (Wn < Wopt), optimum (Wn = Wopt), and wet (Wn > Wopt).

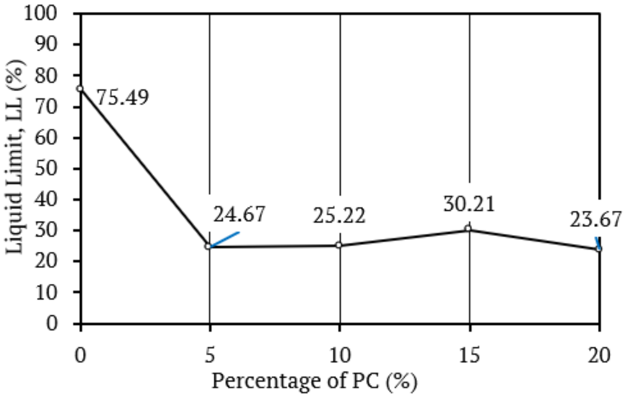


Figure 12 Atterberg behavioral limits of the compacted PC-based weathered clay shale

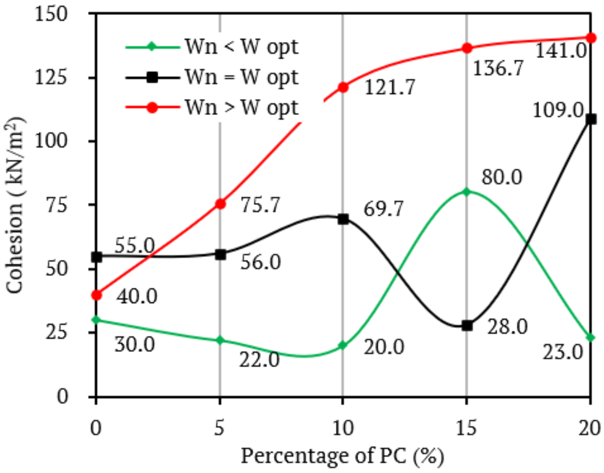


Figure 13 Cohesion behavior of the compacted weathered clay shale with varying PC and moisture content

Based on the results, the increase in cohesion was directly proportional to the PC percentage elevation, especially when the water content was greater than the OMC, as shown in Figure 13. These are often known as the wet and dry sides when the moisture content (MC) is higher and smaller than the OMC. This anomaly was caused by the lack of homogeneity within the PC-based weathered clay shale, due to the utilization of inadequate water on the dry side.

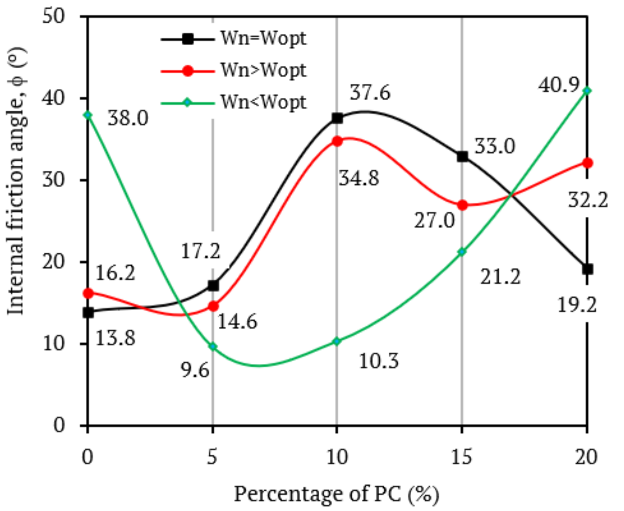


Figure 14 Internal friction angle behavior of the compacted weathered clay shale with varying PC and moisture content

4.3 Normalized Shear Strength

To obtain a general idea of the shear strength (SS) increase in PC-based weathered clay shale, the normalized parameter is defined by the ratio between the deviatoric SS and the cell pressure obtained in the Triaxial Test.

$$\text{Normalized shear strength} = \frac{\Delta\sigma}{\sigma 3} \tag{1}$$

Where, $\Delta\sigma$ and $\sigma 3$ is deviatoric shear stress and cell pressure, respectively. Based on the addition of a 10% PC and 8% OMC, the maximum normalized shear strength increase was obtained at 300%, compared to the original weathered clay shale. This confirmed that the required water content was 8% higher than the OMC when compacting weathered clay shale with varying PC percentages (Table 2)

According to Figure 15, the optimum PC percentage was 10%, due to the unrealistic nature of the 20% mixture that produced the highest normalized shear strength. This 20% PC was assumed to be high because the compacted weathered clay shale was very expensive for utilization as an embankment material.

4.4 Slake Durability Index

Figure 16 shows the durability index (DI) of the compacted weathered sample with various PC

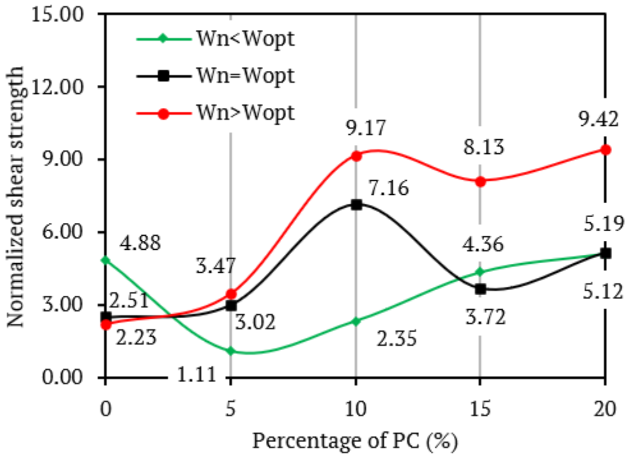


Figure 15 Normalized shear strength behavior of compacted weathered clay shale with varying PC and moisture content.

percentages and moisture content. This indicated that the DI increased to 24% when the weathered claystone was compacted with 10% PC and 8% OMC, compared to the original clay sample. The results also showed that the durability index increase was observed at 33% when the MC was only at the optimum level. However, a drastic decrease was observed when compacted with a moisture content of 4%, which was lower than the OMC.

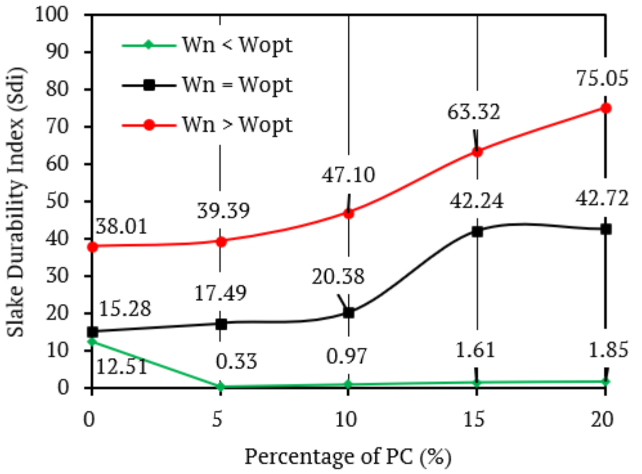


Figure 16 Slake durability index behavior of the compacted weathered clay shale with varying PC and moisture content.

Based on these results, the increase of the moisture content to 8% (optimum) enabled the compacted 10% PC-based weathered clay shale to be 24% better than the original sample. This verified that the durability index increased by 97% with the addition of 20% PC, whose utilization was found to be unrealistic.

5 CONCLUSIONS

The normalized shear strength and durability index were consistently increased for Wn > Wopt or wet side conditions. The addition of 10% PC increased the shear strength ratio by 3 times, compared to the original weathered sample. For example, cohesion and internal friction angle were 121.7 kPa and 34.8° on the wet side, respectively. The administration of 10% PC improved the durability index by 24% with a moisture content of 8%, which was greater than the optimum level. To increase the shear strength and the durability index of the compacted PC-based weathered sample, the required MC was 4-8% greater than the optimum moisture content.

DISCLAIMER

The authors declare no conflict of interest.

AVAILABILITY OF DATA AND MATERIALS

All data are available from the author.

ACKNOWLEDGMENTS

The authors are grateful to Indonesian Society for Geotechnical Engineering (HATTI) for opportunity to participate in 25th Annual National Conference on Geotechnical Engineering 2021.

REFERENCES

Alatas, I. M. (2006), Stabilisasi lempung expansive dengan metoda scmt, *in* 'Perkembangan Terkini Pemanfaatan Cement pada Rekayasa Geoteknik', ISTN-Indocement-HATTI, Manhattan Hotel, Jakarta.

Alatas, I. M. (2016), 'Kesan luluhawa terhadap kekuatan ricih syal lempung dalam penentuan parameter kestabilan cerun'.

Alatas, I. M. (2020), Argillaceous rock slope reinforcement due to failure in cariu west java, Technical report, PT. LTS Geoinves, Jakarta.

Alatas, I. M., Kamaruddin, S. A., Nazir, R., Irsyam, M. and Himawan, A. (2015), 'Shear strength degradation of semarang bawen clay shale due to weathering process', *Jurnal Teknologi* **77**(11).

Alonso, E. and Pineda, J. (2006), 'Weathering and degradation of shales: experimental observations and models of degradation meteorización y degradación de rocas arcillosas: observaciones experimentales y modelos de degradación'.

Castellanza, R. and Nova, R. (2004), 'Oedometric tests on artificially weathered carbonatic soft rocks', *Journal of Geotechnical and Geoenvironmental Engineering* **130**(7), 728–739.

Ciantia, M. and Hueckel, T. (2013), 'Weathering of submerged stressed calcarenites: chemo-mechanical coupling mechanisms', *Géotechnique* **63**(9), 768–785.

Erguler, Z. A. and Shakoor, A. (2009), 'Quantification of fragment size distribution of clay-bearing rocks after slake durability testing', *Environmental & Engineering Geoscience* **15**(2), 81–89.

Himawan, A. (2011), Kajian geoteknik dan usulan teknis kemiringan lereng galian main road sta 22+375 – 22+840, Technical report, PT. Wijaya Karya, Jakarta.

Nazir, R., Alatas, I. M., Kamaruddin, S. A. and Irsyam, M. (2016), 'Effect of weathering on disintegration and shear strength reduction of clay shale', *Jurnal Teknologi* **78**(7-3).

Nicholson, P. G. (2014), *Soil improvement and ground modification methods*, Butterworth-Heinemann.

Purnomo, E. A. (2020), 'Prilaku tanah clay shale yang sudah lapuk distabilisasi dengan semen (studi kasus: Caly shale cariu, jonggol)', Undergraduate Thesis.

Redyananda, A. (2021), 'Pengaruh semen portland terhadap ketahanan tanah clay shale yang telah mengalami pelapukan', Master Thesis.

Sadisun, I. A., Bandono, B., Shimada, H., Ichinose, M. and Matsui, K. (2010), 'Physical disintegration characterization of mudrocks subjected to slaking exposure and immersion tests', *Indonesian Journal on Geoscience* **5**(4), 219–225.

Shakoor, A. and Gautam, T. (2011), Assessing the slaking behavior of clay bearing rock, *in* ‘10th Annual Technical Forum Geo-hazards Impacting Transportation in the Appalachian Region’, Ken State University, Columbus, Ohio.

Wawan, K. et al. (2019), Re-weathering of stabilized clay shale with portland cement behavior, *in* ‘MATEC Web of Conferences’, Vol. 276, EDP Sciences, p. 05009.